

Time & Frequency Bulletin

No. 406 September 1991
(NISTIR 91-3957-9)

National
Institute of
Standards &
Technology



NIST TIME & FREQUENCY BULLETIN

(Supersedes No. 405 August 1991)

NO. 406

SEPTEMBER 1991

1. GENERAL BACKGROUND INFORMATION	1
2. TIME SCALE INFORMATION	1
International Timing Center comparisons via GPS common-view	2
3. UT1 CORRECTIONS AND LEAP SECOND ADJUSTMENTS	2
4. PHASE DEVIATIONS FOR WWVB AND LORAN-C	3
5. GOES TIME CODE INFORMATION	4
6. BROADCAST OUTAGES OVER FIVE MINUTES AND WWVB PHASE PERTURBATIONS	4
7. NOTES ON NIST TIME SCALES AND PRIMARY STANDARDS	5
8. SPECIAL ANNOUNCEMENTS	7

This bulletin is published monthly. Address correspondence to:

Gwen E. Bennett, Editor
Time and Frequency Division
National Institute of Standards & Technology
325 Broadway
Boulder, CO 80303
(303) 497-3295

NOTE TO SUBSCRIBERS: Please include your address label (or a copy)
with any correspondence regarding this bulletin.

1. GENERAL BACKGROUND INFORMATION

ABBREVIATIONS AND ACRONYMS USED IN THIS BULLETIN

APL	- John Hopkins University Applied Physics Laboratory	
BIH	- International Time Bureau, France	
BIPM	- Bureau International des Poids Mesures	
CCIR	- International Radio Consultative Committee	
CRL	- Communications Research Laboratories, Japan	
Cs	- Cesium standard	
CSIRO	- Commonwealth Scientific and Industrial Research Organization, Australia	
GOES	- Geostationary Operational Environmental Satellite	
GPS	- Global Positioning System	
IEN	- National Institute of Electronics, Italy	
INPL	- National Physical Laboratory, Israel	
LORAN	- Long Range Navigation	
MC	- Master Clock	
MJD	- Modified Julian Date	
NIST	- National Institute of Standards & Technology	
NPL	- National Physical Laboratory, England	
NRC	- National Research Council, Canada	
NOAA	- National Oceanic and Atmospheric Administration	
OP	- Paris Observatory, France	
PTB	- Physical Technical Federal Laboratory, Germany	
PRN	- Pseudo random numbers	ns - nanosecond
SI	- International System of Units	μ s - microsecond
TA	- Atomic Time	ms - millisecond
TAI	- International Atomic Time	s - second
TAO	- Tokyo Astronomical Observatory, Japan	min - minute
TUG	- Technical University of Graz, Austria	h - hour
USNO	- United States Naval Observatory	d - day
UTC	- Coordinated Universal Time	
VLF	- very low frequency	
VSL	- Van Swinden Laboratory, Netherlands	

2. TIME SCALE INFORMATION

The values listed below are based on data from the BIH, the USNO, and the NIST. The UTC — UTC(NIST) values are extrapolations since UTC is computed more than two months after the fact. The UTC(USNO,MC) — UTC(NIST) values are averaged measurements from NAVSTAR satellites 3,4,6, and 8 (see references on page 6).

0000 HOURS COORDINATED UNIVERSAL TIME				
AUGUST 1991	MJD	UT1-UTC(NIST) (± 5 ms)	UTC-UTC(NIST) ($\pm 0.2 \mu$ s)	UTC(USO,MC)-UTC(NIST) ($\pm 0.04 \mu$ s)
1	48483	+186 ms	-1.1 μ s	-1.39 μ s
8	48476	+179 ms	-1.1 μ s	-1.36 μ s
15	48483	+167 ms	-1.1 μ s	-1.34 μ s
22	48490	+159 ms	-1.1 μ s	-1.32 μ s
29	48497	+146 ms	-1.1 μ s	-1.31 μ s

INTERNATIONAL TIMING CENTER COMPARISONS VIA GPS COMMON-VIEW

The table below is a weighted average of the indicated GPS satellites used as transfer standards to measure the time difference of Timing Center (i) - UTC(NIST) by the simultaneous common-view approach (see references, page 6). The day-to-day variations of this technique are a few nanoseconds and the accuracy is about 10 ns. The time of the measurement is interpolated to 0000 UTC for the particular MJD ending in 9. The data for NRC and USNO are prepared for the BIPM for the computation of TAI and UTC. The other rows are for general information.

UTC(i) - UTC(NIST) (ns)		MJD			
UTC(i)	PRN NUMBERS	48469	48479	48489	48499
APL	2,3, 11,12,13,14,15, 18, 20,21	-18	-35	-32	41
CRL	3, 11,12	-3257	-3282	-3283	-3287 +
CSIRO	++	-113636	-124326	-133651	-143477@
IEN	11	-130	-84	-126	-121
INPL	11,12,13 20	36678	37951	#	
NPL	11,12,13,14,15,16, 20	-758	-796	-820	-920
NRC+++	3, 11,12,13,14, 16, 18, 20,21	-3203	-3219	-3199	-3187
OP	3, 11,12,13,14,15,16, 20	-216	-208	-226	-261
PTB	3, 11,12,13,14,15,16, 20	-4551	-4536	-4515	-4496
TAO	3, 11,12, 14,15, 17,18, 20	-2204	-2222	-2240	-2289
TUG	11,12,13,14,15,16, 20	1184	879	517	226
USNO	2,3, 11,12,13,14,15, 18, 20,21	-1392	-1349	-1323	-1303
VSL	3, 11,12,13,14,15,16, 20	-2556	-2683	-2784	-2879

+ The value for MJD 48499 for UTC(CRL) was extrapolated forward from MJD 48498.

@ The value for MJD 48459 for UTC(CSIRO) has been updated: the new value is -102796 ns. Also, the value for MJD 48499 was extrapolated forward from MJD 48497.

++ UTC(CSIRO) - UTC(NIST) is computed from the average via CRL, TAO and WWVH.

UTC(INPL) began to steer their clock on MJD 48480. Data were unavailable for MJD's 48489 - 48499.

+++ UTC(NRC) - UTC(NIST) has a differential delay of 41.2 ns; all other comparisons are computed using zero (0).

3. UT1 CORRECTIONS AND LEAP SECOND ADJUSTMENTS

The master clock pulses used by the WWV, WWVH, WWVB, and GOES time code transmissions are referenced to the UTC(NIST) time scale. Occasionally, 1 second is added to the UTC time scale. This second is called a leap second. Its purpose is to keep the UTC time scale within ± 0.9 s of the UT1 astronomical time scale, which changes slightly due to variations in the rotation of the earth.

Positive leap seconds, beginning at 23 h 59 min 60 s UTC and ending at 0 h 0 min 0 s UTC, were inserted in the UTC timescale on 30 June 1972, 31 December 1972-1979, 30 June 1981-1983, 30 June 1985, 31 December 1987, 1989, and 1990. When future leap seconds are scheduled, advance notice will be provided in this bulletin.

The use of leap seconds ensures that UT1 — UTC will always be held within ± 0.9 s. The current value of UT1 — UTC is called the DUT1 correction. DUT1 corrections are broadcast by WWV, WWVH, WWVB, and GOES and are printed below. These corrections may be added to received UTC time signals in order to obtain UT1.

	= +0.2 s beginning 0000 UTC on 20 June 1991
DUT1 = UT1 - UTC	= +0.1 s beginning 0000 UTC on 22 August 1991
	= 0.0 s beginning 0000 UTC on 17 October 1991

4. PHASE DEVIATIONS FOR WWVB AND LORAN-C

WWVB - The values shown for WWVB are the time difference between the time markers of the UTC(NIST) time scale and the first positive-going zero voltage crossover measured at the transmitting antenna. The uncertainty of the individual measurements is $\pm 0.5 \mu\text{s}$. The values listed are for 1300 UTC.

LORAN-C - The values shown for Loran-C represent the daily accumulated phase shift (in microseconds). The phase shift is measured by comparing the output of a Loran receiver to the UTC(NIST) time scale for a period of 24 hours. If data were not recorded on a particular day, the symbol (-) is printed.

The stations monitored are Dana, Indiana (8970 M) and Fallon, Nevada (9940 M). The monitoring is done from the NIST laboratories in Boulder, Colorado.

UTC(NIST) - LORAN PHASE (in μs)				
DATE	MJD	UTC(NIST)-WWVB(60 kHz)	LORAN-C (DANA) (8970 M)	LORAN-C (FALLON) (9940 M)
		ANTENNA PHASE (μs)		
08/01/91	48469	5.72	+0.07	-0.11
08/02/91	48470	5.71	(-)	(-)
08/03/91	48471	5.71	-0.04	+0.18
08/04/91	48472	5.70	(-)	(-)
08/05/91	48473	5.70	(-)	(-)
08/06/91	48474	5.69	-0.04	+0.10
08/07/91	48475	5.70	(-)	(-)
08/08/91	48476	5.65	(-)	-0.60
08/09/91	48477	5.66	(-)	(-)
08/10/91	48478	5.64	-0.37	-0.04
08/11/91	48479	5.62	+0.19	+0.10
08/12/91	48480	5.60	+0.05	-0.15
08/13/91	48481	5.70	-0.04	-0.11
08/14/91	48482	5.68	+0.35	+0.11
08/15/91	48483	5.67	-0.07	+0.09
08/16/91	48484	5.68	+0.09	-0.41
08/17/91	48485	5.68	+0.16	+0.16
08/18/91	48486	5.67	-0.20	-0.24
08/19/91	48487	5.66	-0.07	-0.16
08/20/91	48488	5.63	(-)	(-)
08/21/91	48489	5.74	(-)	(-)
08/22/91	48490	5.74	-0.61	-0.82
08/23/91	48491	5.73	+0.11	-0.15
08/24/91	48492	5.73	(-)	(-)
08/25/91	48493	5.74	-0.19	-0.21
08/26/91	48494	5.74	-0.00	+0.41
08/27/91	48495	5.72	-0.10	-0.19
08/28/91	48496	5.71	+0.10	+0.17
08/29/91	48497	5.71	-0.05	-0.07
08/30/91	48498	5.71	+0.08	+0.27
08/31/91	48499	5.70	-0.21	-0.30

5. GOES TIME CODE INFORMATION

Special Note: On 29 August at 0000 UTC the GOES/East time code was transferred from the GOES-2 satellite to GOES-7. The change was made because of difficulties with maintaining lock of the interrogation channel that carries the time code information and other eclipse-related problems. The change to GOES-7 is at least for the remainder of the eclipse season (through 16 October), but most likely will be permanent. Resulting impacts on GOES/East time code users include the following: (1) receiving antennas will likely need to be repointed toward the new orbital location of 98° W. longitude; (2) loss of signal may occur during the GOES-7 eclipse each day from 0545-0700 UTC through 16 October; (3) time code performance from GOES/East should improve due to the satellite's very small orbit inclination and higher-quality tracking data; and (4) GOES-7 will be repositioned to 108° W. longitude sometime next Spring for the Spring hurricane season in the Pacific. Antennas pointed towards about 103° W. longitude may be able to receive GOES-7 from either orbit location.

A. TIME CODE PERFORMANCE (1 - 31 August 1991)

GOES/East: Performance was mostly within normal limits except for eclipse periods and occasional brief periods when NOAA personnel could not maintain lock of the interrogation channel through GOES-2. At 0000 UTC on 29 August NOAA shifted the GOES/East time code from GOES-2 to GOES-7 located at 98° West longitude.

GOES/West: Performance remained within normal limits during this period.

B. SPECIAL REMINDER: Current satellite locations are about 98° West longitude for GOES/East and 135° West longitude for GOES/West.

C. FALL 1991 ECLIPSE OPERATIONS: The Fall 1991 eclipse period for GOES-7, which now carries the GOES/East time code, will be from 31 August through 16 October. During this period the GOES/East time code may be off from about 0545-0700 UTC each day. The GOES/West time code should not be affected by eclipse operations except for possible brief loss of signal for a few minutes at the beginning and end of eclipse each day.

D. FUTURE SATELLITE LAUNCHES: NOAA's present launch schedule for preplacement of the current East and West satellites has been moved back to October 1992 and April 1993, respectively.

E. GOES STATUS REPORTS

A brief message from the NIST giving current GOES time code status information is available from the U.S. Naval Observatory's Automated Data Service computer system in Washington, DC. To access the new system, dial (202) 653-0068 (commercial) or 653-0068 (FTS). Use 1200 or 2400 Baud only, 8 data bits, and no parity. At the password prompt, type "CESIUM133". At the next prompt, type your name. At the main menu, type "GOES" to get to the GOES submenu. Then type "NISTGO" to receive the status file on GOES. Type "EXIT" or "BYE" to exit the system.

6. BROADCAST OUTAGES OVER 5 MINUTES AND WWVB PHASE PERTURBATIONS

OUTAGES						PHASE PERTURBATIONS WWB 60 kHz				
Station	Aug 1991	MJD	Began	Ended	Freq.		Aug 1991	MJD	Began	Ended
WWVB	14	48482	0302:00	0309.00	2.5		None			
WWV	None						None			
WWVH	None						None			

7. NOTES ON NIST TIME SCALES AND PRIMARY STANDARDS

The frequencies of the time scales, TA(NIST) and UTC(NIST), are calibrated with the NIST primary frequency standards. The UTC(NIST) scale is coordinated within a microsecond of the internationally coordinated time scale, UTC, generated at the BIH. It is used to control all of the NIST time and frequency services. The last calibration of the relative frequency offset, γ , of UTC(NIST) as generated in Boulder, Colorado, gave:

$$1) \gamma_{\text{UTC(NIST)}} (\text{July 1987}) - \gamma_{\text{NBS-6}} (\text{July 1987}) = (-0.6 \pm 2 (1 \text{ sigma})) \times 10^{-13}$$

for the date shown. This calibration includes a correction for the systematic offset due to room temperature blackbody radiation, which is approximately $(\Delta \gamma_{\text{BB}}) = -1.7 \times 10^{-14}$. Using GPS¹, the frequency of TAI for the dates shown were measured to be:

$$2) \gamma_{\text{TAI}} (\text{July 1987}) - \gamma_{\text{NBS-6}} (\text{July 1987 on geoid}) = (+1.7 \pm 2 (1 \text{ sigma})) \times 10^{-13}$$

where account has been taken of the gravitational "red shift."

Starting 1 January 1975, an accuracy algorithm was implemented to bring the second used in the generation of TA(NIST) closer to the NIST "best estimate" of the SI second (see references, p.6). The relative frequency associated with this "best estimate" is denoted $\gamma_{\text{Cs(NIST)}}$. The last calibration (July 1987) covered the period from October 1986 through July 1987.

$$3) \gamma_{\text{Cs(NIST)}} - \gamma_{\text{NBS-6}} = (+1.4 \pm 2) \times 10^{-13} (\text{July 1987})$$

and

$$4) \gamma_{\text{TAI}} - \gamma_{\text{Cs(NIST) on geoid}} = (+0.3 \pm 0.7) \times 10^{-13} (\text{July 1987})$$

This algorithm should provide nearly optimum accuracy and stability for TA(NIST) since it uses all past frequency calibrations with the NIST primary standards. These calibrations are weighted proportionately to the frequency memory of the clock ensemble that generates atomic time. This algorithm, therefore, capitalizes on a weighted combination of all the frequency calibrations with the primary standards in order to gain a "best estimate" of the SI Second while simultaneously obtaining the best uniformity available from the ensemble of working clocks in the atomic time scale system. The relative frequency of TA(NIST) is steered toward $\gamma_{\text{Cs(NIST)}}$ by slight frequency drift corrections of the order of 1 part in $10^{13}/\text{yr}$.

TA(NIST) and UTC(NIST) are no longer simply related by an equation. TA(NIST) is now computed each month using a Kalman algorithm which minimizes the mean square time dispersion. UTC(NIST) is now independently computed using a different algorithm and is steered in frequency to keep its time within a microsecond of UTC(BIH). Table 7.1 lists monthly values of the time difference between UTC(NIST) and TA(NIST). A linear interpolation between monthly values will typically be within 10 ns of the actual time difference, TA(NIST) — UTC(NIST).

The primary standards of NIST (NBS-4 and NBS-6) are used in either of two modes: as calibrators of frequency to provide a reference for the SI second; or as member clocks of the NIST clock ensemble, to help keep the proper time for TA(NIST) and the coordinated time for UTC(NIST). Operating in the clock mode, NBS-4 and NBS-6 are only used and weighted according to their stability performance. Accuracy enters only when they are used as frequency calibrators, in which case clock operation is necessarily interrupted.

¹GPS is the Global Positioning System, a network of navigation satellites.

Table 7.1 is a list of changes in the time scale frequencies of both TA(NIST) and UTC(NIST) as well as a list of the time and frequency differences between TA(NIST) and UTC(NIST) at the dates of leap seconds, and/or frequency or frequency drift changes.

TABLE 7.1

DATE	FREQUENCY CHANGES				
	(MJD)	TA(NIST)	UTC(NIST)	TA(NIST) - UTC(NIST)	$\gamma[\text{UTC(NIST)}] - \gamma[\text{TA(NIST)}]$
1 Mar 90	47951	0	1.00 ns/d	25.045 138 888 s	-6.23 E-13
1 Apr 90	47982	0	1.00 ns/d	25.045 145 580 s	-6.36 E-13
1 May 90	48012	0	1.00 ns/d	25.045 142 241 s	-6.42 E-13
1 Jun 90	48043	0	1.00 ns/d	25.045 143 942 s	-6.34 E-13
1 Jul 90	48043	0	.50 ns/d	25.045 145 580 s	-6.46 E-13
1 Aug 90	48104	0	0.00 ns/d	25.045 147 350 s	-6.62 E-13
1 Sep 90	48135	0	-1.00 ns/d	25.045 149 130 s	-6.69 E-13
1 Oct 90	48165	0	-1.00 ns/d	25.045 150 875 s	-6.82 E-13
1 Nov 90	48196	0	-1.50 ns/d	25.045 152 729 s	-6.94 E-13
1 Dec 90	48226	0	-1.50 ns/d	25.045 154 534 s	-7.04 E-13
1 Jan 91	48257	0	-1.00 ns/d	26.045 156 437 s	-7.05 E-13
1 Feb 91	48288	0	-0.50 ns/d	26.045 158 312 s	-6.92 E-13
1 Mar 91	48316	0	-1.00 ns/d	26.045 159 963 s	-6.69 E-13
1 Apr 91	48347	0	-1.00 ns/d	26.045 161 794 s	-6.46 E-13
1 May 91	48377	0	-1.50 ns/d	26.045 163 589 s	-7.28 E-13
1 Jun 91	48406	0	-1.00 ns/d	26.045 165 515 s	-7.28 E-13
1 Jul 91	48438	0	-1.50 ns/d	26.045 167 426 s	-7.41 E-13
1 Aug 91	48469	0	-1.50 ns/d	26.045 169 422 s	-7.56 E-13

UTC(NIST) is steered in time toward UTC by occasional frequency changes of the order of a few nanoseconds per day; 1 ns/d is approximately 1.16 E-14 . Otherwise, $\gamma[\text{UTC(NIST)}]$ is maintained as stable as possible.

REFERENCES

Allan, D.W., Hellwig, H. and Glaze, D.J., "An accuracy algorithm for an atomic time scale," Metrologia, Vol.11, No.3, pp.133-138 (September 1975).

Glaze, D.J., Hellwig, H., Allan, D.W., and Jarvis, S., "NBS-4 and NBS-6: The NIST primary frequency standards," Metrologia, Vol.13, pp.17-28 (1977).

Wineland, D.J., Allan, D.W., Glaze, D.J., Hellwig, H., and Jarvis, S., "Results on limitations in primary cesium standard operation," IEEE Trans. on Instr. and Meas., Vol.IM-25, No.4, pp.453-458 (December 1976).

Allan, D.W. and Weiss, M.A., "Accurate Time and Frequency Transfer During Common View of a GPS Satellite," Proc. 34th Annual Symposium on Frequency Control, p.334 (1980).

Allan, D.W. and Barnes, J.A., "Optimal Time & Frequency using GPS signals," Proc. 36th Annual Symposium on Frequency Control, p.378 (1982).

8. SPECIAL ANNOUNCEMENTS

AUTOMATED COMPUTER TIME SERVICE (ACTS)

On March 9, 1988, NIST initiated operation of a telephone time service designed to provide computers with telephone access to NIST time at accuracies approaching 1 ms. Features of the service include automated compensation for telephone-line delay, advanced alert for changes to and from daylight savings time and advanced notice of insertion of leap seconds. The ASCII-character time code should operate with standard modems and most computer systems. While the system can be used to set computer time-of-day clocks, simple hardware can also be developed to set other clock systems.

The test phase for this service is now complete and NIST is committed to long-term operation of the service. Additional lines will be added as use expands. NIST requests that calling times be spread out so that the system is not heavily taxed in some narrow time frame (e.g., midnight). The service telephone number is (303) 494-4774. The number may be changed at a later date. A help message can be obtained by returning a ? during the first 6 s of transmission.

With appropriate user software, the NIST-ACTS service provides three modes for checking and/or setting computer time-of-day clocks.

1. In the simplest form of the (1200 Baud) service, the user receives the time code and an on-time marker/character which has been advanced a fixed period to nominally account for modem and telephone-line delays. Accuracy in this mode should be no worse than 0.1 s unless the connection is routed through a satellite.

2. At 1200 Baud, if the user's system echoes all characters to NIST, the round-trip line delay will be measured and the on-time marker advanced to compensate for that delay. The accuracy in this mode should be better than 10 ms. Our experience to date indicates that the asymmetry in conventional, 1200-Baud modems limits the accuracy at this level. Repeatability is about 1 ms.

3. At 300 Baud the user can obtain the same type of service as described in item 2 above, but there is generally less problem with modem asymmetry at this rate and our experience indicates that the accuracy is about 1 ms.

The accuracy statements here are based upon the assumption that the telephone connection is reciprocal, that is, that both directions of communication follow the same path with the same delay. Discussions with telephone carriers indicate that this is the general mode of operation and our tests to date indicate that the lines are both stable and reciprocal.

In order to assist users of the service, NIST has developed documentation of the features of the service, some example software which can be used in conjunction with certain popular personal computers and simple circuitry which can be used to extract an on-time pulse. This material is available on a 5¼-in, 360-kbyte DOS diskette with instructions for \$37.00 from the NIST Office of Standard Reference Materials, B311-Chemistry Bldg, NIST, Gaithersburg, MD, 20899, (301) 975-6776. Specify the Automated Computer Time Service, RM8101. Further technical questions and comments should be directed to NIST-ACTS, NIST Time and Frequency Division, 325 Broadway, Boulder, CO 80303.

46TH ANNUAL FREQUENCY CONTROL SYMPOSIUM

The 46th Annual Frequency Control Symposium will be held May 27-29, 1992 at the Hershey Lodge & Convention Center, Hershey, PA. This symposium has served as the leading technical conference addressing all aspects of frequency control and precision timekeeping. Authors are invited to submit papers dealing with recent progress in research and development. Deadline for submission of summaries is 10 January 1992. For more information contact Mr. Michael Mirarchi or Ms. Barbara McGivney, Synergistic Management Inc., 3100 Route 138, Wall Township, NJ 07719, (908) 280-2024.

BL-114A
(5-90)

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION OR REPORT NUMBER
NISTIR 91-3957-9

2. PERFORMING ORGANIZATION REPORT NUMBER

3. PUBLICATION DATE
September 1991

4. TITLE AND SUBTITLE

Time & Frequency Bulletin

5. AUTHOR(S)

6. PERFORMING ORGANIZATION (IF JOINT OR OTHER THAN NIST, SEE INSTRUCTIONS)

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
BOULDER, COLORADO 80303-3328

7. CONTRACT/GRANT NUMBER

8. TYPE OF REPORT AND PERIOD COVERED

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (STREET, CITY, STATE, ZIP)

National Institute of Standards & Technology
325 Broadway
Boulder, CO 80303

10. SUPPLEMENTARY NOTES

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

The Time & Frequency Bulletin provides information on performance of time scales and a variety of broadcasts (and related information) to users of the NIST services.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

clocks; dissemination; frequency; GPS; oscillators; time

13. AVAILABILITY

☐
☒

UNLIMITED

FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NATIONAL TECHNICAL INFORMATION SERVICE (NTIS).

ORDER FROM SUPERINTENDENT OF DOCUMENTS, U.S. GOVERNMENT PRINTING OFFICE,
WASHINGTON, DC 20402.

ORDER FROM NATIONAL TECHNICAL INFORMATION SERVICE (NTIS), SPRINGFIELD, VA 22161.

14. NUMBER OF PRINTED PAGES

8

15. PRICE

ELECTRONIC FORM

AN EQUAL OPPORTUNITY EMPLOYER

U.S. Department of Commerce
National Institute of Standards and Technology
Time & Frequency Division
Boulder, Colorado 80303

FIRST-CLASS MAIL
POSTAGE & FEES PAID
NIST
Permit No. G195

OFFICIAL BUSINESS
Penalty for Private Use, \$300

GWEN BENNETT
DIVISION 847 COPY 9
NIST
325 BROADWAY
BOULDER, CO 80303